EVALUATION OF EFFECTIVENESS PARAMETERS ON GAS DEHYDRATION PLANT (SIMULATION)

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ABSTRACT

The transportation of natural gas through pipeline is an important aspect in the world. However the combination of hydrocarbon and water under suitable condition form hydrates in pipeline. These hydrates will cause blockage of pipeline. Gas dehydration is the method used to remove water from the hydrocarbon for the smooth transfer of natural gas in pipeline around the world. This research describes the effectiveness parameters on gas dehydration plant. The parameters studies are gas flow rate, absorber pressure and number of equilibrium stages of an absorber in liquid triethylene glycol (TEG) dehydration units. ASPEN HYSYS is used for steady state simulation, design, performance monitoring and optimization of oil and gas production, gas processing and petroleum refining industries. Peng-Robinson equation of state and MESH equation are chosen in the system. In conclusion, the results showed that increasing gas flow rate decreases the dehydration efficiency. While, dehydration efficiency decreases with increasing of operating pressure. Increasing of equilibrium stages increases the dehydration efficiency.

ABSTRAK

Penghantaran gas asli melalui saluran paip adalah satu aspek yang penting di dunia . Tetapi kombinasi hidrokarbon dan air dalam keadaan yang sesuai menghasilkan hidrat di talian paip. Hidrat ini akan menyebabkan penyumbatan saluran paip . Gas dehidrasi adalah kaedah yang digunakan untuk mengeluarkan air dari hidrokarbon supaya penghantaran gas asli melalui saluran paip menjadi lancar di seluruh dunia. Kajian ini menerangkan keberkesanan parameter untuk kilang dehidrasi gas. Parameter yang dikaji adalah kadar aliran gas , tekanan mesin penyerap dan beberapa peringkat keseimbangan mesin penyerap dalam cecair Trietilena glikol (TEG) unit dehidrasi. ASPEN HYSYS digunakan untuk simulasi keadaan mantap , reka bentuk, pemantauan prestasi dan pengoptimuman pengeluaran minyak dan gas , pemprosesan gas dan industri penapisan petroleum. Persamaan Peng –Robinson dan persamaan MESH diguna untuk simulasi kajian ini. Kesimpulannya , semakin tinggi kadar aliran gas semakin menurun kecekapan dehidrasi . Selain itu, kecekapan dehidrasi berkurangan dengan peningkatan tekanan mesin penyerap. Meningkatkan peringkat keseimbangan meningkatkan kecekapan dehidrasi .

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LIST OF ABBREVIATIONS

L	Liquid molar flow rate
X	Mole fraction in liquid phase
F	Feed molar flow rate
l	Liquid phase
K	Equilibrium constant
H_i	Fractional molar enthalpy of component *i* in liquid phase
H_i^+	Fractional molar enthalpy of component *i* in ideal gas state
φ_i^v	Fugacity coefficient of gas phase
γ_i	Activity coefficient
P	Pressure
V	Molar volume
T	Temperature
R	Universal gas constant (8.314 $J.K^{-1}.mol^{-1}$)
T_c	Critical temperature
P_c	Critical pressure
α	Alpha function (function of reduced temperature)

LIST OF ABBREVIATIONS

CO_2	Carbon dioxide
EOS	Equation of State
H_2O	Water
H_2S	Hydrogen sulfide
MEG	Monoethylene Glycol
DEG	Diethylene Glycol
TEG	Triethylene Glycol
TREG	Tetraethylene Glycol
SI	International System of unit
PFD	Process Flow Diagram
BTEX	Emission of Aromatic, e.g. Benzene, toluene, ethylbenzene, xylenes
VOC	Volatile Organic Compounds

CHAPTER 1

INTRODUCTION

1.1 Motivation and statement of problem

The combination of hydrocarbon and water under appropriate condition crystallize to form solid called hydrates in pipeline. It causes problem in the transfer of hydrocarbon gases in the piping system. These hydrates block the piping system from flowing smoothly and cause imbalance pressure in the pipe. Hydrates form at high pressure and temperature far above water freezing point. Gas hydrate has a cage like structure containing a molecule from the hydrocarbon. This cage is formed by water through hydrogen bonding (Christensen, L,. 2009). Besides that, when water have contact with acid gas from the natural gas, corrosion of pipeline will occur. Hence, water must be remove from hydrocarbon gases in the piping system. In order to do that, Gas Dehydration is a common process used to remove water (H_2O) from natural gas hydrocarbons.

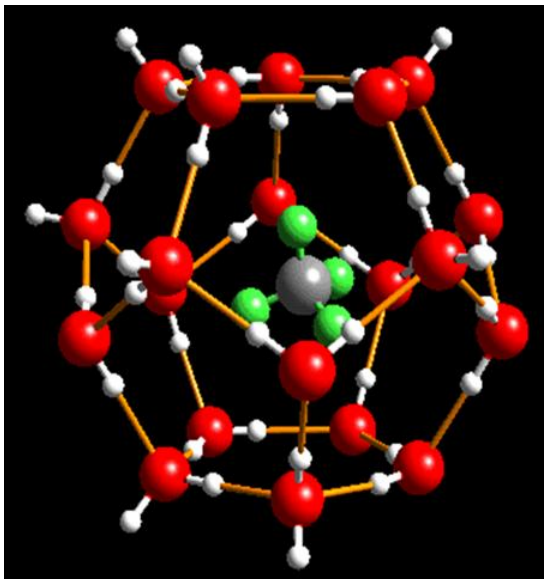

Figure 1-1: Molecule of a hydrate

Figure 1-2: Hydrates in a pipe

This study focused on studying the effectiveness parameters on absorber of a gas dehydration plant. The parameters were gas flow rate, absorber pressure, absorber temperature and number of equilibrium stages of an absorber in liquid triethylene glycol (TEG) dehydration units.

According to Mohamadbeigy K. (2007) study, he studied the effective parameters of glycol flow rate, reboiler condition and number of equilibrium stages of absorber. The number of equilibrium stages, glycol flow rate and lean glycol are interrelated. The higher the number of equilibrium stages the lower the glycol flow rate or lean glycol

concentration is needed. From his study result, he found out that increasing the equilibrium stages allows the gas to reach equilibrium with the lean glycol at lower glycol flow rate. Besides that, the reboiler temperature influences the overhead water content by changing the purity of the lean glycol.

As for Kazemi P. and Hamidi R. (2010) research, they divided the gas dehydration process to two parts, gas dehydration and solvent regeneration. The parameters they study was number of equilibrium stages, reboiler temperature, stripping gas, temperature of inlet gas to absorption column CO_2 and H_2S content of inlet gas and TEG flow rate. They found the same result as Mohamadbeigy K. (2007), which the reboiler temperature affect water content of inlet gas with modifying of regenerated TEG. Furthermore, increasing the equilibrium stages lead to equilibrium the water content of wet gas and inlet TEG to the absorber at low TEG flow rates. Besides that, the used of scrubber to remove liquid decreases the amount of water that has to remove in the absorber. This action decreases the column size and even decrease the TEG needed in the process.

The previous researchers were more focused on the overall effectiveness parameters of the gas dehydration plant. As this study is more focus on the effectiveness parameters in absorption column. This study is done to get the most efficient absorber parameters and with these parameters we can generalize the whole dehydration plant.

1.2 Objectives

The objective of this research is to evaluate the effectiveness parameters on natural gas dehydration plant using Aspen HYSYS.

1.3 Scope of this research

The scope of this study was to identify the effectiveness parameters such as gas flow rate, absorber pressure, absorber temperature and number of equilibrium stages of an absorber in liquid triethylene glycol dehydration units.

In the HYSYS glycol package, the temperatures, pressures and gas compositions normally come across in a glycol plant. This applies for contactor for temperatures from 15 to 50 ℃ and pressures between 10 and 100 bars (Christensen, L,. 2009).

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This paper presents the experimental studies of natural gas dehydration using absorption method. TEG as the absorbent used in gas dehydration. There were many previous studies done by other researcher. The commonly parameters they study were theoretical stages of absorber, glycol circulation rate and regeneration condition. Glycol was more of their focus. As for this study was focus on the overall efficiency of the absorber parameters. Hence, more study on absorber parameters were taken out and discuss in subchapter below.

2.2 Introduction of Dehydration

Eventually, there are four methods used in gas dehydration process. The methods are absorption, adsorption, membrane processes and refrigeration. In absorption, it uses a liquid with high affinity for water to absorb water. The glycol is the commonly used liquid in absorption. As for adsorption, it uses adsorbents like silica gel to adsorb water. Next, membrane processes using membrane to separate water when the gas passes the membrane. Lastly, refrigeration cools the gas and makes the water condense. Then the condense water is remove in a separator (Christensen, L,. 2009).

The comparison of these four methods, the best and most commonly used in gas dehydration plant is absorption method. In membrane processes, it require higher amount of cost and it less efficient compare to absorption and adsorption methods. While for refrigeration, although it operate at low cost but it is not efficient. As for absorption and adsorption methods, these two are the most efficient method in gas dehydration plants. However, absorption is chosen because it is more economical and less energy is required to operate it (Kidnay, A., and William, R., 2006; Christensen, L,. 2009).

As I mention earlier, glycols are commonly used absorbents in dehydration plants. This is because it has high affinity for water. This can increase the absorption efficiency. The most generally used glycol in dehydration plants is triethylene glycol (TEG). It has higher boiling point and lower vapor pressure compare to monoethylene glycol (MEG) and diethylene glycol (DEG). Besides that, it is more economical when compare to tetraethylene glycol (TREG). The higher polymers than TREG have higher viscosities which are usually not used for dehydration (Christensen, L,. 2009).

Table 2-1: Properties for MEG, DEG, TEG, TREG and water. (Christensen, L,. 2009)

	MEG	**DEG**	**TEG**	**TREG**	**Water**
Formula	$C_2H_6O_2$	$C_4H_{10}O_3$	$C_6H_{14}O_4$	$C_8H_{18}O_5$	H_2O
Molar mass (kg/kmol)	62.07	106.12	150.17	194.23	18.015
Normal boiling point (℃)	197.1	245.3	288.0	329.7	100.0
Vapor pressure @ 25℃ (Pa)	12.24	0.27	0.05	0.007	3170
Density @ 25℃ (kg/m^3)	1110	1115	1122	1122	55.56
Viscosity @ 25℃ (cP)	17.71	30.21	36.73	42.71	0.894
Viscosity @ 60℃ (cP)	*5.22*	7.87	9.89	10.63	0.469
Maximum recommended regeneration temperature (℃)	163	177	204	224	-
Onset of decomposition (℃)	-	240	240	240	-

There are several equipment is commonly used in a gas dehydration plant. There are absorber, boiler, flash separator, heat exchanger, regenerator, stripper and pump. Generally glycol dehydration is a continuous process. The used glycol is recycled to use back as absorbent. The general process flow is shown at Figure 2-1 below. The wet gas

and glycol flow counter currently through the absorber. Wet gas enters from the bottom while glycol enters from the top of the absorber. Glycol will absorb water from the wet gas when they in contact in the absorber. Dry gas will exit at the top of the absorber and it is use to cool the incoming lean glycol while rich glycol exits at the bottom of the absorber. This rich glycol flows to a flash separator to separate the hydrocarbon gases which remain in it. Next, it flows towards regenerator or stripper to get rid of the water in the rich glycol stream. Finally the lean glycol is recycled back to the absorber.

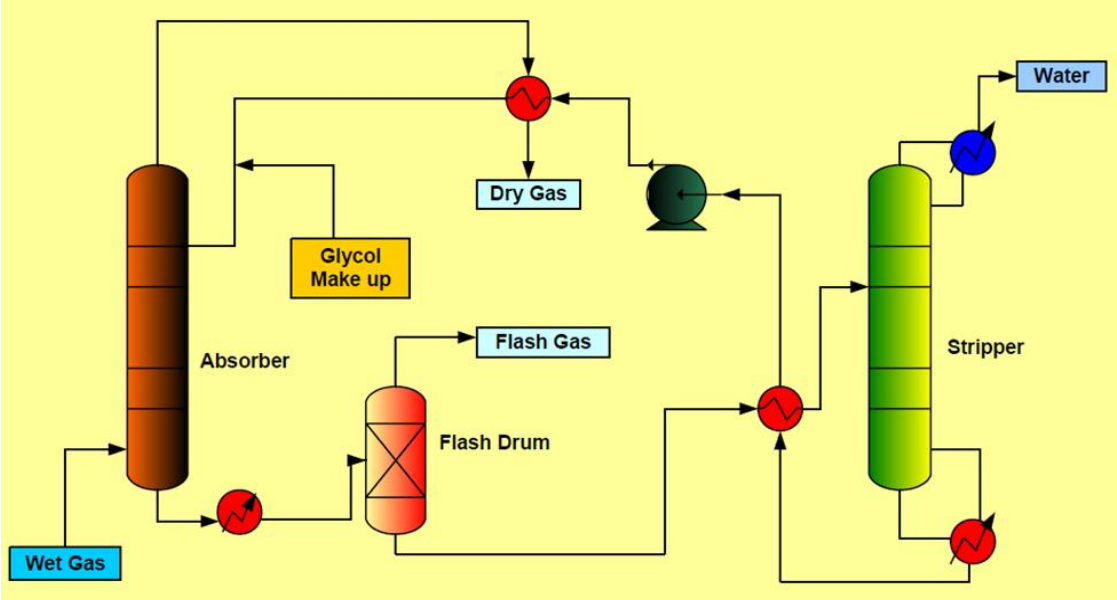

Figure 2-1: General process flow of a glycol dehydration unit (Mohamadbeigy, K., 2007).

2.3 Previous work on Absorption of Gas Dehydration

According to Engineering Data Book (2004b), gas hydrate will form at higher temperature than sub cooled water. Hence at lower temperature, the true equilibrium condensed phase is gas hydrate. This is also means the hydrate formation will occur at 15 to 20 ℉ (8 to 10 ℃) higher than the dew point seen from Figure 2-2 below. Moreover, Engineering Data Book (2004b) mention the actual error depends on temperature, gas composition and pressure but pressure effect is not much. Figure 2-2 below from Engineering Data Book (2004b) shows that dehydration increase with lower absorption temperature. The range of typical operating absorber inlet temperature is 16 to 38 ℃ and operating pressure is below 140bar (Engineering Data Book, 2004b). It also mentions

that lower temperature improves absorption efficiency but will cause hydrate formation at high pressure.

Refer to both Engineering Data Book (2004b) and Manning F. and Thompson R. (1991), absorber temperature can be as high as 66 ℃ but above 38 ℃ will cause unacceptably vaporization losses for glycol solutions while temperature lower than 10 ℃ will cause high viscosity on glycol solution and reduce column efficiency. In order to reduce the hydrocarbon condensation into the glycol, the glycol inlet temperature in absorber must be 3 to 11 ℃ higher than the inlet gas temperature (Manning, F., and Thompson, R., 1991; Kidnay, A., and William, R., 2006).

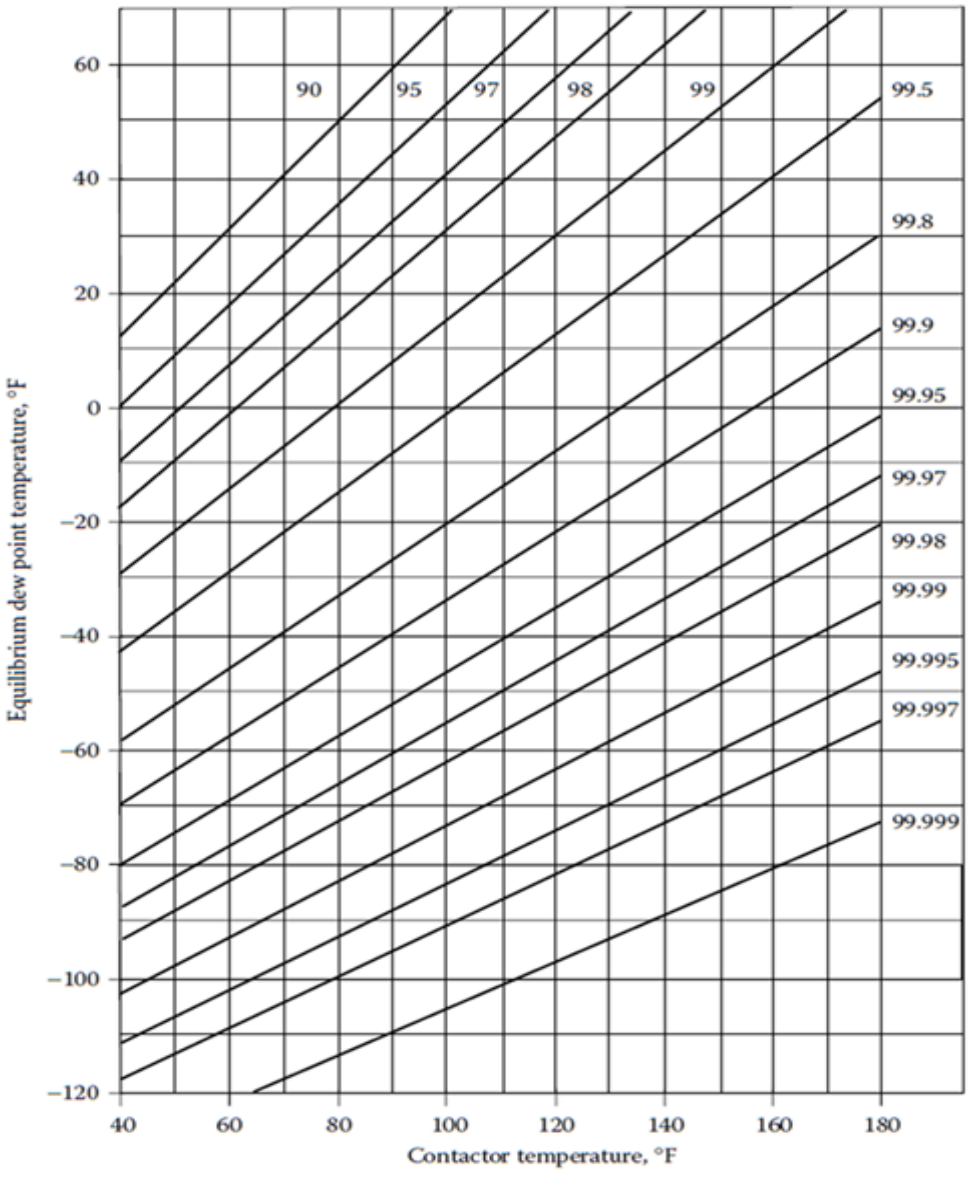

Figure 2-2: Equlibrium water dew point as a function of contactor temperature and TEG concentration wt% (Engineering Data book, 2004b).

Kazemi P. and Hamidi R. (2010) found that inlet gas temperature is important parameter which will affect the TEG flow rate and decrease gas density. This cause inlet gas has higher volumetric flow rate. They said all these happen because higher temperature of inlet gas increases its water content exponentially. This can be seen from Figure 2-3 below (Kazemi, P., and Hamidi, R., 2010).

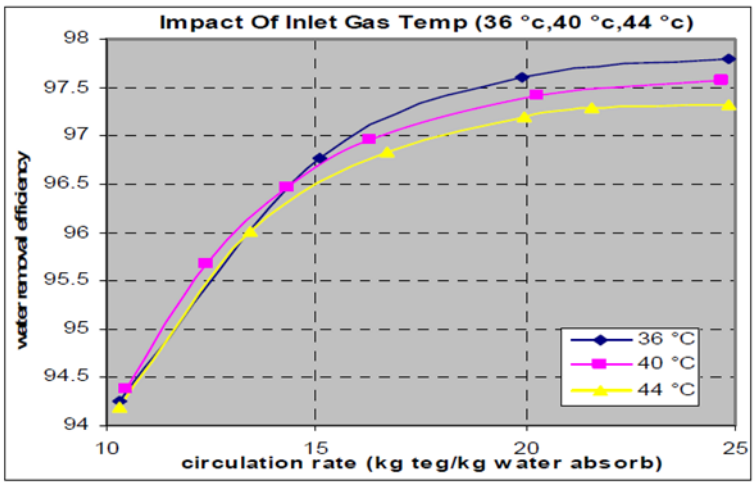

Figure 2-3: Effect of inlet gas temperature on water removal efficiency (Kazemi, P., and Hamidi, R., 2010).

Other than that, Kazemi P. and Hamidi R. (2010) researched that higher equilibrium stages result to equilibrium the water content of wet gas and inlet TEG to the absorption column at low TEG flow rate. Figure 2-4 below was the result taken from Kazemi P. and Hamidi R. (2010) study. It showed that for three and four equilibrium stages, the TEG flow rates were 20 (kg TEG/ kg (water absorbed)) and 18 (kg TEG/ kg (water absorbed)) respectively. As for two equilibrium stages, it need higher TEG flow rate to reach equilibrium.

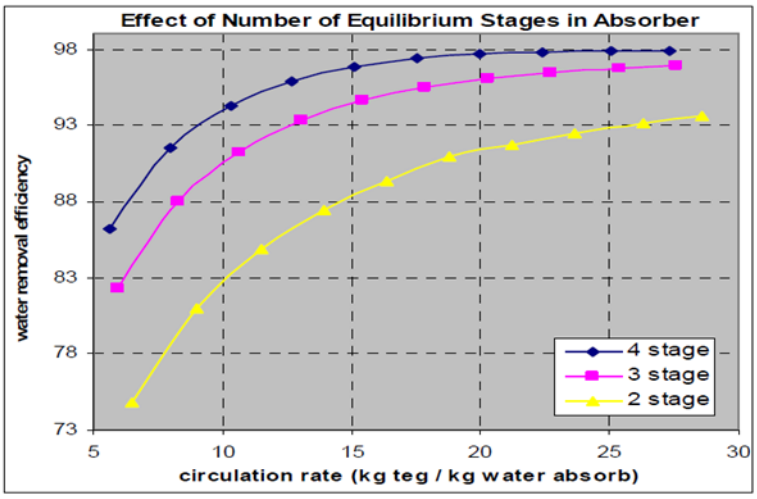

Figure 2-4: Effect of equilibrium stages of absorption column on water removal efficiency (Kazemi, P., and Hamidi, R., 2010).

Mohamadbeigy K. (2007) have a same result as Kazemi P. and Hamidi R. (2010) study on effect of the number of equilibrium absorber stages on residual water content. The result was higher number of equilibrium stages in absorber allows the gas to reach equilibrium at lower TEG flow rate. In another words, higher TEG flow rate is prefer when only one ideal stage is used. The result can be seen from Figure 2-5 below (Mohamadbeigy, K., 2007). Higher flow rate is preferred because it increases the contact between the inlet gas and TEG.

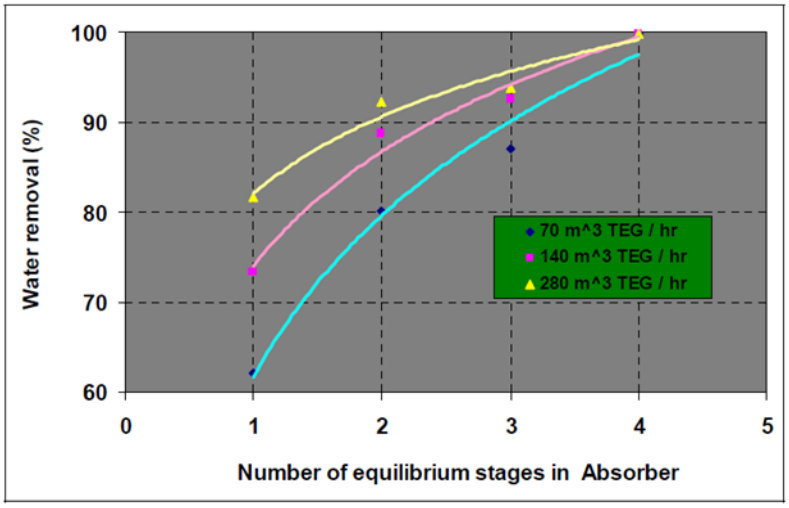

Figure 2-5: Water removal versus number of equilibrium stages in the absorber (Mohamadbeigy, K., 2007).

According to Mohamadbeigy K. (2007), percentage of water removal of the inlet gas decreases with increasing pressure of the absorber and higher number of equilibrium

stages in absorber have higher percentage of water removal. This is done at constant temperature with variable number of equilibrium stages in absorber. The result can be seen from Figure 2-6 below (Mohamadbeigy, K., 2007). Furthermore, he mentions that absorber required less wall thickness to contain the pressure as the absorber operate at low pressure condition. Hence, it can save cost by adjusting the operating condition and contactor thickness.

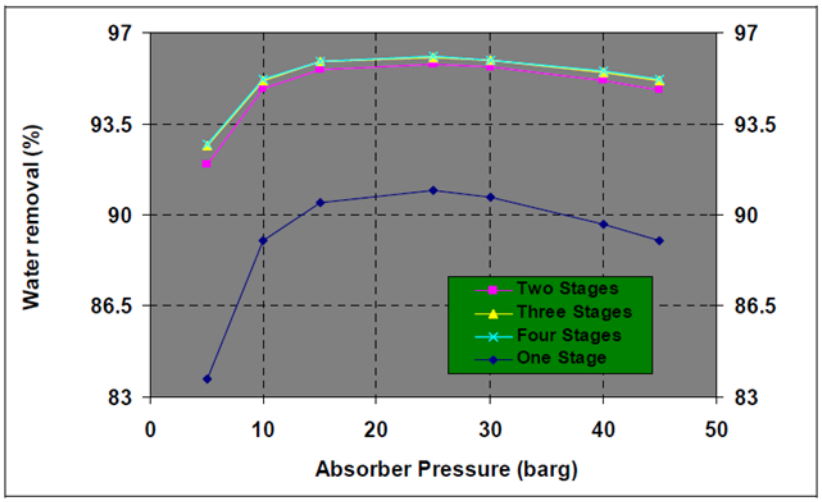

Figure 2-6: Effect of pressure in the contactor on the water content of gas stream (Mohamadbeigy, K., 2007).

2.4 Summary

This paper presents studies of gas dehydration which were more focus on the parameters of the absorber. For instance, theoretical stages in absorber, natural gas flow rate, absorber temperature and pressure. The results of the study by most researchers were similar by means of concept wise. The difference was only the level of efficiency of the percentage of water removal. One of the results was the higher the number of equilibrium stages and flow rate of inlet gas, the higher is the water removal efficiency. Besides that, the overall water removal efficiency will decrease with the increase of the absorber pressure.

CHAPTER 3

MATERIALS AND METHODS

3.1 Overview

This paper presents the process simulation, absorption model and input data used for this research. The simulation was Aspen HYSYS. Aspen HYSYS was chooses because it contain all the dehydration unit natural gases needed for this study. Plus, it was in hand in handling system which comprises hydrocarbon and water over a wider range of temperature and pressure. There were two type of absorption model used. They were Peng-Robinson equation of state and MESH equation.

3.2 Process Simulation

Aspen HYSYS will be the program simulation used for this research. The version of HYSYS used for the process simulations in this report is Aspen HYSYS 2006.5. HYSYS is mainly use for steady state simulation, design, gas processing, petroleum refining industries, performance monitoring and optimization of oil and gas production. Hence, it is suitable to use for this research which deal with gas dehydration (HYSYS User Guide, 2005).

It is very important in selecting the right Fluid Package in HYSYS. As all the necessary information related to pure component flash and physical property calculations of the components is right within the selected Fluid Package (HYSYS User Guide, 2005).

There is a Fluid Package which contains all the dehydration unit natural gases wanted for this research. Furthermore, Peng-Robinson equation of state is chosen as an ideal model for process calculation. This is because it is suitable in handling system which comprises hydrocarbon and water over a wide range of temperature and pressure.

In HYSYS User Guide (2005), it mentions that material streams are used to show the travelling of material between different units of operations. It is essential to define the main properties and composition in each material stream. Some of the main properties are pressure, temperature, composition and molar flow rate. These properties are the main parameters for this study. As for the energy streams, it is use to show the energy travelling between different units of operations. Specify dynamic information can be view through the energy stream. Heat flow is the main parameter for energy stream (HYSYS User Guide, 2005).

Besides that, HYSYS simulation program have all the unit operators used in a gas dehydration plant. There are absorber, flash drum, separator, heat exchanger and pump. Each of these unit operators can be set to the operation condition as the gas dehydration plant.

3.3 Absorption Model

In this study, Peng-Robinson equation of state is used to represent the thermodynamic behavior of the TEG water system (Polak, L., 2009). This model is based on a cubic equation of state. This model is selected because it has a good phase equilibrium estimates over a variations of temperature and pressure. This is essential in terms of modeling the multicomponent system in a natural gas dehydrations plants as it is necessary to account for the existence of gases in the absorption column (Peng, D., Y., Robinson, D., B., 1976).

The Peng-Robinson equation is commonly used for hydrocarbons and related components over variations of temperature and pressure. According to Polak, L., (2009), Peng-Robinson is precise for calculating enthalpy and entropy departures, liquid densities, vapor densities and vapor-liquid equilibrium in natural gas processing and others petroleum related operations. Plus it is accurate in the critical region.

The Peng-Robinson equation is as below:

$$P = \frac{RT}{(V-b)} - \frac{a.\propto}{V(V+b)+b(V-b)} \quad (3.1)$$

Where,

$$a = 0.45724\frac{R^2{T_c}^2}{P_c},$$

$$b = 0.07780\frac{RT_c}{P_c},$$

P = pressure,

V = molar volume,

T = temperature,

R = universal gas constant (8.314 $J.K^{-1}.mol^{-1}$),

T_c = critical temperature, P_c = critical pressure,

P_c = critical pressure,

$$\alpha = alpha\ function, function\ of\ reduced\ temperature\ T_r = \frac{T}{T_c}$$

$$= [1 + (0.37464 + 1.54226\omega - 0.26992\omega^2)(1 - (\tfrac{T}{T_c})^{0.5})]^2 \quad (3.2)$$

$$\omega = -log\left(\frac{P}{P_c}\right) - 1 \quad (3.3)$$

Another model is the MESH equations. It contains of four sets of equations. There are mass balances, equilibrium relations, sum of mole fractions of each phase and heat balance. Mesh is used to describe tray columns treatment (Kasiri, N., and Hormozdi, Sh., 2005). Material balance of component i on tray j, for liquid phase is as follows (Seader, J.D., and Henley, E.J., 1998):

$$L_j x_{i,j} - L_{j+1} x_{j+1} - F^l{}_{i,j} = 0 \quad (3.4)$$

Where,

L = liquid molar flow rate,

x = mole fraction in liquid phase,

F = feed molar flow rate,

The superscript l = liquid phase

Equilibrium relation for component *i* at tray *j* is as below:

$$K_{i,j} = y_{i,j} / x_{i,j} \quad (3.5)$$

Where,

K = equilibrium constant

Sum of mole fraction of each phase is as follows:

$$\sum_{i=1}^{N} y_{i,j} = 1 \, , \sum_{i=1}^{N} x_{i,j} = 1 \quad (3.6)$$

Energy balance equation is shown as follows:

$$L_{j+1} H_{Lj+1} + V_{j-1} H_{Vj-1} + F_j H_{Fj} - L_j H_{Lj} - V_j H_{Vj} - Q_j = 0 \quad (3.7)$$

Kasiri, N., and Hormozdi, Sh., (2005), mention that the real enthalpy of components is calculated by combination of ideal gas enthalpy and residual enthalpy of gases and liquids. Ideal gas enthalpy is calculated by:

$$H^{ig}_i = a' + b'T + c'T^2 + d'T^3 + e'T^4 + f'T^5 \quad (3.8)$$

Where, *a', b', c', d', e'* and *f'* could be found in literature (Prausnitz, J., et al., 1999).

The general form of gas and liquid residual enthalpy are as below:

$$\frac{H - H^{ig}}{RT} = \frac{1}{RT} \int_0^P [\forall - T(\frac{\partial \forall}{\partial T})_P] dP \quad (3.9)$$

$$(\frac{\partial Ln f_i^l}{\partial T})_{P,x} = -\frac{\bar{H}_i - H_i^+}{RT^2} \quad (3.10)$$

Where,

$\bar{H}_i$ and H_i^+ = fractional molar enthalpy of component *i* in liquid phase and ideal gas state respectively.

Wilson activity model is used for estimate of liquid phase treatment. The following equation could be applied to evaluate fugacity coefficient of gas phase (φ_i^v) from Peng-Robinson equation of state and activity coefficient (γ_i) from Wilson activity model (Kasiri, N., and Hormozdi, Sh., 2005) :

$$\gamma_i \varphi_i^v P = x_i \gamma_i P_i^{sat} \varphi_i^{sat} \quad (3.11)$$

3.4 Input Data

The input data used for this study is from Azaloye gas field in Iran.

Table 3-1: Simulator input data from Azaloye gas field in Iran (Kasiri, N., and Hormozdi, Sh., 2005).

Wet Gas	
Components mole fraction	
Water	0.001420
CO_2	0.013200
H_2S	0.000001
N_2	0.035200
CH_4	0.853000
C_2H_6	0.055400
C_3H_8	0.023500
i-C_4H_{10}	0.004600
n-C_4H_{10}	0.006690
i-C_5H_{12}	0.001890
n-C_5H_{12}	0.001762
C_6^+	0.003920
Benzene	0.000045
Toluene	0.000030
Flow rate *(kmol/hr)*	2403.00
Pressure *(bar)*	73.20
Temperature *(°C)*	40.00
Lean TEG	
Components mole fraction	
TEG	1.00
Flow rate *(kmol/hr)*	104.46
Pressure *(bar)*	71.20
Temperature *(°C)*	45.00